Mesoscale Processes in Tropical Cyclones

PI Dr. Greg J. Holland
Co-PIs Dr. Yuqing Wang, Dr. Peter May, and Jeff Kepert
Bureau of Meteorology Research Centre,
PO Box 1289K, Melbourne, Vic 3001,
Australia
Ph: +61-3-9669-4501, Fax: +61-3-9669-4660
g.holland@bom.gov.au

Award Number: N-00014-94-1-0493

Web site: http://www.bom.gov.au/bmrc then Mesoscale Meteorology

LONG-TERM GOALS

To develop improved understanding and prediction of the atmosphere, with particular emphasis on severe weather. A special emphasis is placed on coastal zones and observing-system research.

OBJECTIVES

To investigate the impact of mesoscale processes on the motion and development of tropical cyclones by: 1. theoretical studies using quasi-analytic and numerical modelling methods; 2. diagnostic analysis of data.

APPROACH

We have adopted a stratified research approach, including use of quasi-analytic methods to provide hypotheses and indications of the potential processes, followed by application to sophisticated numerical experiments and diagnostic examination of actual tropical cyclones. We aim to support direct operational implementation of our findings.

The group is interacting closely with a number of groups. We are formally affiliated with several Australian Institutions through the Tropical Cyclone Coastal Impacts Project. We have recently established a collaboration with the University of Rhode Island (Isaac Ginis) on coupled ocean-atmospheric effects on tropical cyclones. Informal collaboration exists with the NOAA/AOML Hurricane Research Division, the Naval Postgraduate School, and the University of Hawaii (Bin Wang).

WORK COMPLETED

Over the course of this research program we have made substantial progress on understanding several aspects of tropical cyclone motion and development, including: the tendency for meandering motion about a mean path; the interactions of tropical cyclones with the environment and with other tropical cyclones and mesoscale circulations; the baroclinic effects on tropical cyclone motion; questions of tropical cyclone predictability; thermodynamic estimation of tropical cyclone intensity; and new methods of data assimilation tuned towards mesoscale applications.

Highlights of this research include a comprehensive analysis of the manner in which atmospheric vortices can interact (Lander and Holland 1993, Ritchie and Holland 1993, Holland and Dietachmayer 1993, Wang and Holland 1994), together with the first research results on the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**
4. TITLE AND SUBTITLE **Mesoscale Processes in Tropical Cyclones**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Bureau of Meteorology Research Centre,PO Box 1289K,Melbourne, Vic 3001, Australia,**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

presence of mesoscale vortices in tropical cyclones and their effect on motion and development (Holland et al. 1992, Holland and Lander 1992, Ritchie et al. 1993, Holland and Lander 1993). The larger-scale interactions during formation and develoment of tropical cyclones in a monsoon environment have been reviewed by Holland (1995). This showed the complex interactions between a monsoon depression, westward travelling easterly waves, and recently developed tropical cyclones in defining the environment for development, intensificaton and movement of tropical cyclones.

We have developed a full primitive equations model to support our basic research activities. During 1998, this has been extended to include a more complete mixed ice-phase microphysical scheme for moist convection, which can provide more realistic modelling of the tropical cyclone core and rain-band structure and their interactions (Wang 1998).Indeed, much of the important dynamics can only be captured with the cloud microphysics explicitly included.

RESULTS

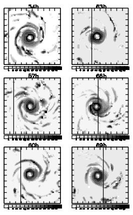
Our research during 1998 has found that (1) both the tendency for meandering motion about a mean path and the intensity change may result from the interactions with the rainbands, and with other embedded mesoscale circulations; (2) temporary weakening-intensification of some observed landfalling tropical cyclones, such as Hurricane Andrew 1992 in Miami, may be caused by the eyewall replacement process initiated by land interactions; (3) Inclusion of spray evaporation reduces the intensification rate of a developing tropical cyclone but has little effect on the final intensity of the system; (4) potential vorticity generation in rainbands may provide a major source for the core region.

Highlights of this research include a recognition of direct and indirect interactions at the mesoscale. The direct interaction includes the processes that directly modify the core convection, such as the SST under the eyewall, external vertical wind shear. The indirect interaction is dominated by lateral interaction with the rainbands or other embedded mesoscale circulations.

Lateral interaction between the core convection and an outer rainband can cause substantial intensity changes. When a rainband develops some distance away from the cyclone core, the cyclone will weaken due to the well recognised barrier effect on the boundary layer inflow. However, some rainbands are found to propagate spirally toward the cyclone core and enhance the core convection, leading to rapid intensification of the cyclone. This may be linked to the production of mid-level potential vorticity in the bands.

Diagnostic analysis of profiler observations taken during TCM90 have been completed during 1998. We have found a substantial generation of potential vorticity in the mid-level stratiform region of rainbands (May and Holland 1998). This generation is sufficient to develop a mid-level jet of 30 ms^{-1} in several hours. This may represent a significant source of vorticity for the storm as a whole because the vorticity continues to be generated as air is advected towards the core and the height of the potential vorticity decreases significantly with the warming of the air at closer radii.

This lateral interaction is being extended to understand the intensity change of landfalling tropical cyclones and the effect of SST anomalies in the near environment of a tropical cyclone. We have found from our preliminary numerical experiments that when the tropical cyclone’s circulation impinges on the coast, moisture convergence, and cumulus convection may be enhanced there (Fig. 1). As time proceeds, the convective cells rotate cyclonically around the cyclone centre and a new spiral rainband develops. At this stage the band inhibits low level inflow and the core intensity decreases. However, as the rainband impinges upon the cyclone core, the convection is enhanced and leads to a short period of rapid intensification, with an eyewall contraction. As the eye crosses the coast, the primary eyewall collapses, leading to weakening as the cyclone moves inland.



1Figure 1. Model simulated radar reflectivity at the surface for a tropical cyclone moving towards the coast (vertical line). The domain shown in each panel is 300km by 300km. A rainband initially formed on the landward side. This initially decreases the cyclone intensity, but the cyclone reintensifies after the band merges with the eyewall.

The processes described above are also applicable to a cyclone which moves towards a local warm SST anomaly. In this case, the cyclone will first weaken due to the development of outer rain band over the warm SST, and then intensify as the developed rainbands are spiraled inward and impinge upon the cyclone core (Fig. 1).

The potential impact of the sea spray evaporation on tropical cyclone intensification has also been examined using our tropical cyclone model. We have found that spray modifies the core convection and produces a tendency to reduce the intensification rate of the model tropical cyclone, but there is only minor affect on the final intensity of the cyclone (Fig. 2).

As discussed in the next section, this concept is being further developed using a combination of modelling and observational analyses. The potential contribution of the potential vorticity generated in the rainbands to the intensification and intensity change processes are being undertaken using the results from our very high resolution tropical cyclone model.

IMPACT/APPLICATIONS

Our strategic research is aimed at improved understanding and improved predictability of the intensity and movement of tropical cyclones. To ensure good feedback with operational staff, we maintain a regular program of seminars and discussions at major operational centers.

2Fig. 2 Time evolution of the minimum surface pressure (solid) and maximum lowest model level wind in the experiments with (thick) and without (thin) the effect of sea spray evaporation. Note that the inclusion of sea spray slows the intensification rate, but doesn't affect the final intensity.

TRANSITIONS

Our numerical model was coupled with the ocean model at the University of Rhode Island. Our initialization scheme for model tropical cyclones is being used by the BMRC Limited Area Modelling Group for sensitivity case studies.

RELATED PROJECTS

We have collaborated with Bin Wang at the University of Hawaii and with Isaac Ginis at the University of Rhode Island on coupled ocean-atmosphere modeling of tropical cyclones.

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Only a selection of publications are included. A full set may be found on our web page.

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